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Health's Contribution to Economic Growth in an Environment of Partially Endogenous Technical Progress

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Abstract

Technical progress – the generation or adoption of new technologies – underpins long term economic growth yet the empirical growth literature has devoted surprisingly little attention to two key questions: How much of the (huge) cross-country variation in growth rates results from differences in rates of technical progress? And, second, what factors account for differences in countries' rates of technical progress? This paper develops and applies a parsimonious growth model that incorporates selected determinants of both technological level and its rate of change. We do this in the context of an assessment of the magnitude and nature of health's consequences for growth.

The paper partitions reasons for cross-country variation in income levels into three components: (i) persistent factors influencing the level of output; (ii) time varying factors influencing the level of output (e.g. levels of physical capital); and (iii) persistent factors influencing a country's rate of technical progress. Persistent factors are ones that remain unchanged (e.g. geographical location) or that change only slightly in the time period under study (e.g. potentially endogenous determinants of technical progress such as a country's orientation toward free trade). Multi-level modeling techniques using maximum likelihood methods were used for estimation.

Using data on 53 countries over the period 1965-90 we find:

1. In our sample of 53 countries the mean rate of technical progress for the period 1965-90 was -0.1% per annum. The standard deviation was 1.16%.

2. Economies that were fully open by the measure we use experienced rates of technical progress that were 1.4 to 1.7% per annum higher than those that were closed.

3. An entirely tropical country could expect to have an income level 27-37% lower than an otherwise similar country in a temperate zone. Countries that are highly coastal (as measured by fraction of land area within 100km of the coast) exhibit no shift in income level but can expect a substantially higher rate of technical progress.

4. Accumulation of physical capital and education accounted for 67% and 14%, respectively, of total growth. Education's effect could plausibly be modeled either through its effect on income level or on the rate of technical progress.

5. Improvements in health (as measured by the survival rate of males between age 15 and age 60) accounted for about 11% of growth during the period. Our framework allows us to conclude that health's effects were on income levels, not on changing the rate of technical progress.

A supplementary analysis extended our data set to the year 2000 for 48 of the 53 countries in the original data set. Results were broadly similar although the magnitudes of the coefficients on geographical variables decreased and, on health, slightly decreased.

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Health's Contribution to Economic Growth in an Environment of Partially Endogenous Technical Progress [*]

by
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Much of the existing empirical economic growth literature models growth rates over a substantial period – often measured in decades – as a function of initial conditions in a country and aspects of the country's policy regime, investments, and institutional characteristics during the period. Barro (1997, pp. 7-8) observed that this class of models precludes assessment of the role of the generation and diffusion of new technology even though technical change is widely viewed as central to long-run growth (e.g. Easterly and Levine, 2000). Indeed, as Bernard and Jones (1996) have pointed out, much of the empirical literature at least implicitly assumes that technical progress is exogenous at a rate that is constant across countries. Our primary purpose in this paper is to relax this assumption in order to assess potential determinants of the rate of technical progress. Within an aggregate production function framework, we use multi-level modeling techniques to assess human capital, geographical and policy related determinants of how much and why the rate of technical progress differs from one country to another. We find that the rate of technical progress (from either the adoption or the generation of new technologies) varies markedly across countries and is related to both geographical and policy variables. In this sense technical progress can be viewed as partially (but only partially) endogenous. Some previous work has relaxed the assumption of homogeneity across countries in long-term rates of technical progress (e.g. Boskin and Lau, 1992 and 2000, Dougherty and Jorgenson, 1996, and Lee, Pesaran and Smith, 1997) and found great heterogeneity. We build on their work and extend it with an exploratory assessment of reasons for cross-country variation in rates of technical progress.

A growing literature – perhaps beginning with Myrdal (1952) - provides insight into the nature and magnitude of health's effects on development. Our second purpose in this paper is to add to that literature by estimating the magnitude of the effect of improved health on gross domestic product per capita using data from 53 countries over the period 1965 to 1990.[1, 2] The

[*] An early version of this paper was presented at a seminar at the Harvard Center for International Development (CID) in April 1998 and at the World Health Organization (WHO) Director-General Transition Workshop at CID in June of 1998. We are indebted to participants in those workshops -- particularly David Bloom, David Canning, Jeffrey Sachs and Peter Timmer -- for valuable comments. We are also indebted to Alok Bhargava, William Easterly, Bengt Muthen, Jennifer Ruger and Christopher Spohr for valuable discussions. Christopher Murray and Lant Pritchett provided useful reminders concerning the caveats that must be attached to cross-country analyses and the data on which they are based. John Gallup provided us with several of the geographic and economic policy variables from the data base assembled at CID. Working Group 1 of the WHO Commission on Macroeconomics and Health and the Fogarty International Center of the U.S. National Institutes of Health (NIH) supported preparation of this paper.

[1] This paper was commissioned by WHO and the NIH and for this reason we pay particular attention to health's effects on growth.

paper provides estimates of the contribution of better health – as measured by improvements in adult survival rates (for males) – by incorporating health into a meta (or aggregate) production function framework and by decomposing growth to assess the component due to mortality decline. This is within the spirit of augmentation of the Solow growth model along lines initiated by Mankiw, Romer and Weil (1992), but extended to assess whether health's effects operate through changing output levels directly or through affecting the rate of technical progress.

In what follows we first review available evidence on health's contribution to economic growth, which can in principle arise either from shifting the level of productivity or from facilitating technical progress. After discussing data and methods the paper then turns to its main findings on determinants of outcome levels and of the rate of technical progress. A final brief section uses these results to decompose growth into its sources, including health, technical progress and the component of technical progress that we identify as endogenous.

1. Background: Health and Economic Growth

The World Bank's World Development Report for 1993, *Investing in Health*, begins by summarizing the enormous and unprecedented gains in health in the second half of the 20th century:

> "In 1950 life expectancy in developing countries was forty years; by 1990 it had increased to 63 years. In 1950 twenty-eight of every 100 children died before their fifth birthday; by 1990 the number had fallen to 10. Smallpox, which killed more than 5 million annually in the early 1950s has been eradicated entirely."[3]

The contribution to human welfare of this transformation may be difficult to value in monetary terms, but it is certainly huge.[4] To the extent that improved health is an ultimate objective of development, that objective is being well met. Health improvements contribute, moreover, to other development objectives. Ill health reduces learning and school attendance; it increases absenteeism and lowers productivity at work; it may lead to premature retirement and in other ways decrease the ratio of a country's working population to its non-working population; it attenuates incentives to acquire education or to invest in physical capital; and, Bloom and Sachs (1998, p.13) have argued, widespread ill health in a country may create an adverse climate for international trade and foreign direct investment.

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[2] A number of reviews conclude there to be an important effect of health on economic development. See Bloom and Canning (2000), World Health Organization (2001) and Ruger, Jamison and Bloom (2001). A major recent review of the determinants of growth treats health's role only in passing, however, and conveys skepticism about its importance (Temple, 1999).

[3] See World Bank (1993, p.1).

[4] Although monetary valuation of health gains may be difficult, Nordhaus (2003) has used published estimates of the "value of a statistical life" to generate estimates of the contribution of mortality decline to the rate of improvement of overall economic welfare in the United States (or "full income"). He concluded that the magnitude of the contribution in recent decades was about the same as the welfare gain resulting from growth in output of goods and services. Jamison, Sachs and Wang (2001) utilized similar methods to conclude that the economic impact of the AIDS epidemic in Africa is far greater that is typically estimated through assessment of its impact on GDP. Bloom, Canning and Jamison (2004) provide a brief overview of the literature (mostly very recent) on health and full income.

Studies of the effects of health on income growth or productivity divide naturally into three categories. The first comprises historical case studies that may be more or less quantitative. The second comprises studies at the individual or household level; these "micro" studies involve either household surveys that include one or more measures of health status along with extensive other information or they involve assessment of the impact of specific diseases (or disease control programs). The third category – into which the present study falls – utilizes cross-national data to assess the impact of measures of health at the national level on income level, income growth rates or investment rates.

Robert Fogel and collaborators have been introducing assessment of the health and nutrition status of populations into a series of studies of the economic history of Europe. Health status serves both as an indicator of population welfare and, in some of the studies, as a determinant of economic growth rates. Fogel (1997) provides an overview with extensive reverences to the relevant literature. From this literature Fogel concludes that health and nutrition improvements may have accounted for between 20 and 30% of Britain's income growth rate of about 1.15% per capita per annum in the 200-year period 1780-1979.

Studies at the individual and household level are, increasingly, corroborating the historical findings. Strauss and Thomas (1998) provide a major review (extensively updated by Thomas, 2001), and Savedoff and Schultz (2000) overview methods used in the household studies and summarize findings of a recent analyses from five Latin American countries. Illustrative studies include econometric work from West Africa (Schultz and Tansel, 1997), from Mexico (Knaul, 2000), from China (Liu et. al., 2003) and from Vietnam (Laxmimarayan, 2004). Rather different in approach are an epidemiological study of the consequences of disability in the Netherlands (Stronks et al., 1997) and assessments of the interplay between disability and public assistance in the United States (Burkhauser, Haveman and Wolfe, 1993; Brady, Meyers and Luks, 1998).

Cross-country studies of the impact of health on income levels and growth rates go back at least to the first of the World Bank's World Development Reports (WDRs) on poverty (World Bank, 1980; Hicks, 1979; Wheeler, 1980). Findings were suggestive of the importance of health but not definitive. Work undertaken by two of the present authors (DTJ and LJL) as background for the Bank's WDR on *Investing in Health* (World Bank, 1993, p.21) found stronger effects of health using better data and an aggregate production function methodology. More recent studies have examined the effects of life expectancy in around 1965 on economic growth in the subsequent 15 to 25 years (Barro, 1997; Sachs and Warner, 1997; Bloom and Williamson, 1998). These studies consistently found strong positive direct effects as well as indirect ones operating through rates of investment in physical capital or demographic profiles of populations. Meltzer (1992) reviewed and extended the literature on the effects of mortality levels on investments in education and concludes that the effect may be substantial. Bhargava et al (2001) assessed the effects of initial health status on growth over a shorter period (5 years) in a panel of countries and likewise found strong effects, but only in low-income countries. An intriguing recent finding suggests that high levels of malaria morbidity may have a substantial growth retarding effect even when controlling for life expectancy (Gallup and Sachs, 2001).

Issues of data quality and causality will continue to place caveats on findings of cross-country studies such as those just described and those reported in this paper. Easterly et al. (1993) point to the volatility of growth performance of countries relative to their basic characteristics and suggest that much variation may be due to luck or exogenous shocks (e.g. in terms of trade) rather than to levels of education, say, or adequacy of economic policy. This is a useful caution, but recent work with better data and a broader range of determining variables (e.g. Bloom and Williamson, 1998; Boskin and Lau, 2000) does suggest that the cross-country data contain lessons for policy. The lessons are far more credible, though, when corroborated by microeconomic studies, as is increasingly the case.[5]

In what follows we extend the cross-country literature on health's effects to an aggregate production function framework that allows for cross-country variation in the rate of technical progress. This allows us to test the hypothesis that health's effect on economic outcomes results from its role in explaining why some country's rates of technical progress are high (versus its role in changing the level of productivity).

2. Data

Our main study – for 53 countries over the period 1965-90 – utilized data on PPP-adjusted income and on physical capital per capita from the Penn World Tables (version 5.6) (Heston & Summers, 1996; Summers & Heston, 1991). Annex 2 of this chapter reports an updating study, (on 48 of the original countries for the period 1960 – 2000), and uses data from Penn World Tables version 6.1 and other more recent sources. These numbers are expressed in 1985 international dollars, adjusted for purchasing power.[6] The mortality measures are from the World Development Indicators (World Bank, 2001); and education data are from Barro and Lee (1996). We use the most recent Barro-Lee dataset for average years of schooling attained per male between age 15 and 60 as a proxy for human capital.[7] Geographical variables (what percent of the country lies in the tropics and how coastal the country is), as well as a measure of economic openness are from the Harvard Center for International Development. We include geographical variables in our analysis in light of recent findings strongly suggestive that tropical and isolated countries face additional barriers to growth (Sachs and Warner, 1997; Bloom and Williamson, 1998). These same studies provide empirical support for the importance of open economies, as do several more specific studies (e.g., Edwards, 1998; Frankel and Romer, 1999). Hence our inclusion of openness (**open6590**).

Bloom and Williamson (1998) concluded that population growth affects economic growth principally when the dependent and working-age populations have different growth rates. In light of their research finding, we included the total fertility rate (**tfr**) in the model to proxy the characteristics of the country age structure; countries with high TFR will tend to have a high ratio of dependent to working age population which, in the production function formulation, should adversely affect per capita output levels.

[5] In addition to the health-related household level studies reviewed by Thomas (2001) there are firm-level studies of productivity (e.g. Barley and Solow, 2001) that broadly corroborate related country-level estimates of productivity levels (e.g. Lau, 1996, pp. 85-86).

[6] In related work with Bhargava (Bhargava et al 2001) we explored effects of health on short-term growth in both international dollars from PWT and in income converted to dollars at exchange rates from World Bank data sets. Results were broadly similar. For a full discussion, see Bhargava (forthcoming).

[7] Kreuger and Lindahl (2001) assess the reliability of the Barro-Lee and alternative education series, all of which they conclude contain substantial measurement error (sufficient to induce a downward bias in their education coefficient of up to 40%). Annex 2 uses an improved education series in its analyses, that appears substantially less subject to measurement error (Cohen and Soto, 2001).

One difference between the data here and what is more typically used is that we employ a health measure specific to the working age population, i.e. a measure of mortality rates between age 15 and age 60 (Bos et al., 1998).[8] These data, from the World Bank, reflect reasonably good vital registration data for some countries, but for others the numbers are generated from demographic models based on survey data. Resulting measurement error would tend to attenuate estimates of effect size. Demographers label the probability of dying in the 45 years following age 15 (at prevailing age-specific mortality rates) as 45q15, usually expressed per thousand rather than percent. We explored use of 45q15 but concluded that it was somewhat preferable to use *survival* probabilities instead. For our sample as a whole, the 1970 adult survival rate (**asr**) for males, i.e. the probability of surviving to age 60 from age 15 was 687 (per thousand) and increased to 755 by 1990. (Equivalently 45q15 decreased from 313 to 245 in this period.) Life expectancy is, of course, simply a weighted average of mortality rates at all ages — but it is strongly influenced by infant and child mortality rates that are presumably less relevant for current productivity.

As with life expectancy, however, adult survival rates can only proxy for the morbidity and disability rates that affect worker productivity (or propensity to retire early from the labor force — see Handa and Neitzert, 1998). The other effects of mortality are through loss of human capital in productive ages – thereby adversely affecting the dependency ratio (Bloom and Williamson, 1998) – or adversely affecting incentives to invest in physical or human capital (Barro, 1997; Radelet, Sachs and Lee, 1997, pp. 45-46).

Table 1 provides the overall means and standard deviations of the variables used in this analysis; means of these variables in 1965 and 1990 are also included in the Table to give the reader a sense how the variables have changed across time. (Country-specific values for the data in 1965 and 1990 appear in Annex Table 1.1) The analysis on the determinants of income level is based on the 53 countries for which we had data on physical capital stocks. Although selecting the countries with data available on physical capital potentially biases the sample, our comparison (using traditional growth prediction models) with a larger selection of countries (Table 2) suggests that although some differences exist, they are not major.

3. Methods

In order to model income level in a panel data set we used the "meta-production function" approach as developed by Lau and his co-workers in a series of studies of the sources of economic growth in both industrialized and East Asian countries.[9] For an overview of their

[8] Bhargava et al (2001) previously used adult survival rates and found **asr** to be a better predictor of growth rates than life expectancy. Mayer et al (2001) also found mortality rates over different age intervals in the adult range to perform better than life expectancy. Meltzer (1992) earlier used a somewhat different measure of adult survival, the expected number of productive years lived per adult, defined as age 15 to 65.

[9] Islam (1995) develops methods for analyzing economic growth in a panel of countries with an emphasis on accounting for country fixed effects. Mayer et al (2001) report results from Latin America using Islam's approach. Lee, Pesaran and Smith (1997) extend Islam's work by allowing for country-specific rates of technical progress and, additionally (1998) provide a succinct account of the similarities and differences between their approach and his. Kreuger and Lindahl (2001) extend the work of Lee et al in a different way by allowing for heterogeneity in the coefficient of education on growth.

Table 1. Variable Definitions, Means and Standard Deviations, Overall and for 1965 and 1990 (53 countries)

Variable	Defintions	Overall		1965		1990	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Time-varying Variables							
ypc	income per capita, in 1985 international $ (adjusted for purchasing power)	5725	4449	4031	3130	7431	5497
kpc	physical capital per capita, in 1985 international $ (adjusted for purchasing power)[a]	5977	6297	3241	3356	8839	8394
med	average education of male population aged 15 and over	6.12	2.60	5.02	2.50	7.24	2.37
asr	adult survival rate, per thousand (for males)[b]	759	108	720	125	803	95
tfr	total fertility rate[c]	3.90	2.01	4.83	1.96	2.98	1.61
time	year of observation minus 1965	12.42	8.52				
lypc	natural logarithm of **ypc**	8.27	0.94	7.95	0.90	8.53	0.98
lkpc	natural logarithm of **kpc**	8.93	1.35	8.35	1.42	9.34	1.28
lasr	natural logarithm of **asr**	6.62	0.16	6.56	0.19	6.68	0.14
ltfr	natural logarithm of **tfr**	1.22	0.54	1.48	0.44	0.96	0.50
	number of available observations (overall or indicated time period)	**316**		**53**		**53**	
Time-invariant Variables							
g6590	growth rate of **ypc** between 1965 and 1990, expressed as % per annum	2.1%	1.6%				
tropics	fraction of the country's land area situated in the geographical tropics	41.0%	47.0%				
coastal	fraction of the country's land area located within 100km of the sea coast or an ocean-navigable waterway	54.0%	36.0%				
open6590	fraction of years between 1965 and 1990 that the country is deemed to have an open economy	54.0%	45.0%				
	number of countries	**53**					

[a] Physical capital per capita is calculated using the non-residential capital stock per worker (in 1985 international prices), numbers of workers, and the size of population variables in the Penn World Tables.

[b] The adult male survival rate is defined as the probability that a male of age 15 would survive to age 60 given the then-prevailing age-specific mortality rate for males, expressed per thousand males alive at age 15. (i.e. **asr** is 1000 minus 45q15, the more typically available demographic indicator of the probability of dying in the 45 years following the 15th birthday, expressed per thousand.)

[c] The total fertility rate is the expected number of children a woman will have throughout her lifetime at the then-prevailing age-specific fertility rates.

Table 2. Determinants of Economic Growth Rates, 1965-90

Independent variable	Countries analyzed in this paper 1	2	Larger group of countries 3	4
constant	-0.16	-0.11	-0.14	-0.12
	(2.05)	(1.37)	(1.91)	(2.02)
lypc (1965)	-0.016	-0.018	-0.019	-0.019
	(4.08)	(5.80)	(5.09)	(6.86)
lasr (1965)	0.049	0.035	0.049	0.039
	(3.22)	(2.77)	(4.02)	(3.92)
med (1965)	0.002	0.001	0.003	0.002
	(1.93)	(1.65)	(2.66)	(1.88)
ltfr (1965)	-0.016	0.012	-0.017	0.008
	(2.05)	(1.60)	(2.40)	(1.21)
tropics		-0.015		-0.012
		(3.07)		(2.77)
coastal		0.009		0.009
		(1.91)		(2.05)
open6590		0.028		0.029
		(6.17)		(6.71)
R-square value	39%	71%	39%	68%
Number of countries	53	51	80	75
Chi-square Or F value	7.56	14.72	11.87	19.98
Associated P-value	0.00	0.00	0.00	0.00

Notes:

1. The dependent variable is **g6590**, the rate of growth of income per capita (**ypc**) between 1965 and 1990, expressed as percent per annum. All equations are estimated with ordinary least squares (OLS).
2. Columns 1 and 2 are estimated for the same countries that were used in the analyses reported in Tables 3 and 4. Columns 3 and 4 report analogous results for the entire group of countries with available data (educational data were the mos frequently missing) and relate more closely, therefore, to the published literature (see, for example, Sachs and Warner, 1997, table 2).
3. t-values are in parenthesis below the estimated coefficients.

methods and findings, see Lau (1996) and Boskin and Lau (1992 and 2000). Within the meta-production function framework alternative estimation procedures can be used to analyze panel data across countries. If data are available for many time points for a sufficient number of countries, the flexibility of the transcendental logarithmic (translog) production function allows estimation of critical country-specific parameters (e.g. rates of technical progress) and also allows separation of the level and bias of technical progress from scale effects. Boskin and Lau (2000) apply the translog specification to 40 years of annual data from the G-5 countries. They find substantial importance for different rates of technical progress in determining long-term differences in growth rates across the large high-income countries and that technical progress is both physical and human capital augmenting (and, therefore, importantly endogenous in that it is affected by countries' savings rates and educational investments).

Our analysis includes many developing countries in a much larger sample of countries than was studied by Boskin and Lau. This limits data availability to 5-year intervals and precludes use of the highly data intensive translog formulation. In this paper we instead estimate a Cobb-Douglas or variants of a Cobb-Douglas specification. In order to allow, however, for cross-country variation in technical progress (or diffusion), as a critical source of variation in rates of long-term growth, we explore use of a multi-level modeling technique, specifically, version 5 of the Hierarchical Linear Modeling (HLM) technique developed by Bryk and Raudenbusch (1992).[10] This maximum likelihood procedure allows us to model country-specific intercepts and the associated complex error structure. This specification of HLM is similar to a generalized least squares (GLS) estimated random effects model when we impose a common production function across countries (while allowing the intercept to vary). We also employ a more generalized HLM procedure that allows estimation of country-time interactions (i.e. of country-specific technical progress in a Cobb-Douglas framework) and central to the purposes of this paper, it allows us to assess determinants of cross-country variation in technical progress. (Temple, 1999, points to parameter heterogeneity in general as a major problem to be dealt with in the empirical growth literature. We address it explicitly only for technical progress.)

Most of the previous literature has used specifications that impose common coefficients across countries, but as explained in the introduction, we believe that important sources of cross-country differences in income growth result not only from different investment rates but, even more importantly, from *persistent* differences in the characteristics of countries. Our work is thus in the spirit of Hall and Jones (1997, 1999) who observe that it "…is the fixed effect itself that we are trying to explain." (Hall and Jones, 1997, p.174.) Our work generalizes theirs in also seeking to model persistent country differences in the rate of acquiring and using new technologies.[11] In order to capture this phenomenon, our aggregate production function is given by equation (1) supplemented with equations (3) and (4), which are estimated simultaneously with equation 1, and which seek to explain the country-specific intercepts (β_{0i}) and rates of technical progress (β_{1i}) in equation (1):

[10] Kreft and de Leeuw (1998) provide a more general and introductory account of multi-level modeling and Raudenbusch et al (1999) document the software package that we use.

[11] Easterly (2001, chapter 3) and Easterly and Levine (2000) place the role of technical progress and diffusion more centrally than we do. Factor accumulation rates, particularly of physical capital, vary enormously across countries and the resultant differences in growth rates over periods of decades are, in our view, more significant than implied by Easterly. That said, this paper provides empirical evidence supporting the central role of technological change in explaining cross-country differences in long run growth rates and levels of income.

(1) $\textbf{lypc}_{it} = \beta_{0i} + \beta_{1i}\,\textbf{time}_t + \beta_2\,\textbf{lkpc}_{it} + \beta_3\,\textbf{med}_{it} + \beta_4\,\textbf{lasr}_{it} + \beta_5\,\textbf{ltfr}_{it} + \varepsilon_{it}$,

where the variables and coefficients signify:

$\textbf{lypc}_{it}$: the natural log of average per capita GDP in country i over a five-year period from t-2 to t+2 ;

$\textbf{time}_t$: the number of years lapsed since 1965 (t-1965)

$\textbf{lkpc}_{it}$: the natural log of average per capita physical capital in country i over a five-year period from t-2 to t+2 ;

$\textbf{med}_{it}$: the average number of years of education in the male population, aged 15 and over, of country i at time t ;

$\textbf{lasr}_{it}$: the natural log of the male survival rate in country i at time t ;

$\textbf{ltfr}_{it}$: the natural log of the total fertility rate in country i at time t ;

β_{0i} : the country-specific intercept for country i;

β_{1i} : the effect of 'technical progress' in increasing income per capita in country i ;

β_2 : the elasticity of income with respect to per capita physical capital;

β_3 : the responsiveness of per capita income with respect to changes in male education;

β_4 : the elasticity of income with respect to adult male survival rate;

β_5 : the elasticity of income with respect to total fertility rate; and

ε_{it} : unexplained residual for country i at time t , assumed to be normally distributed with mean 0.

Table 1 provides definitions, means and standard deviations for the variables used in the analysis.

Assuming a common intercept and time coefficient for all countries (i.e. assume $\beta_{0i} = \beta_{0j}$ and $\beta_{1i} = \beta_{1j}$ for all i , j), equation 1 has the model specification for an ordinary-least-squares (OLS) regression. To make the above equation similar to a random-effects regression, to be estimated by generalized least squares, one can supplement equation 1 with:

(2) $\beta_{0i} = \gamma_{00} + \mu_{0i}$,

where μ_{0i} is assumed to be normally distributed with mean zero and uncorrelated with the unexplained residual for the country ε_{it}, in other words, the covariance between them is zero [$\mathrm{Cov}(\mu_{0i}, \varepsilon_{it}) = 0$]. This allows estimation of country-specific intercepts since the random variable μ_{0i} is the deviation of country i's mean from the overall mean. To model potential *determinants* of the country intercept we can use the random-intercept specification in HLM:

(3) $\beta_{0i} = \gamma_{00} + \gamma_{01}\,\textbf{tropics}_i + \gamma_{02}\,\textbf{coastal}_i + \mu_{0i}$.

As explained above and in Table 1, the right-hand-side variables chosen here denote the fraction of a country's land area situated within the geographical tropics (**tropics**) or within 100 km from the seacoast or an ocean-navigable waterway (**coastal**), respectively.

HLM also provides a practical Bayesian algorithm for modeling potential determinants of coefficients on other variables and, because of the central importance of technical progress, we modeled its coefficient (i.e. the coefficient on time) as a function of **tropics**, **coastal** and **open6590**:

(4) $\beta_{1i} = \gamma_{10} + \gamma_{11}\,\mathbf{tropics}_i + \gamma_{12}\,\mathbf{coastal}_i + \gamma_{13}\,\mathbf{open6590}_i + \mu_{1i}$.[12]

The actually estimated values of the parameters indicate, for example, to illustrate the interpretation of equations (3) and (4), that tropical countries' income levels are shifted downward (γ_{01} is negative). We consistently found little effect of **coastal** in equation (3) or of **tropics** in equation (4) and, in the next section, we report only results from more parsimonious specifications that delete those variables from the relevant equations.

4. Statistical Results

Tables 3 and 4 report the main results of our analysis based on estimation of an aggregate production function for 53 countries based on data at 5-year time intervals between 1965 and 1990. Before turning to those results, however, Table 2 reported growth equations in a form more closely related to much of the literature, i.e. it reports predictors of countries' growth rates between 1965 and 1990 (**g6590**) in terms of conditions in 1965 and other variables. More elaborate variants of these models appear in the literature with extensive discussions (e.g., Barro, 1997, Sachs and Warner, 1997). Our purpose in reporting these estimates is two-fold. First, models 1 and 2, which are estimated on the same data set of countries as the rest of our models, indicate the potential importance of most of the variables we are examining and that these variables behave more or less as they are reported to do in the published literature, including the openness and geographical variables (model 2). Second, availability of data on the value of a country's physical capital stock per capita limits the number of countries in our analysis to 53, but this variable is not used in the growth prediction literature. Models 3 and 4 in Table 2 report results of estimating the same equations as in models 1 and 2 with data from the substantially larger number of countries typically reported on. The reported effects of education levels and adult survival rates are somewhat larger in models 3 and 4 than in models 1 and 2. The (peculiar) reversal of sign on total fertility rate associated with going from model 1 to model 2 also occurs in going from model 3 to model 4. While we have no explanation for this our main point is to observe that the sample of countries for which we have data on physical capital seems to represent the larger sample reasonably well.

Tables 3 and 4 report our main statistical results. Table 3 presents the basic estimates of aggregate production functions. Table 4 goes beyond Table 3 by reporting on our estimates of the magnitude of selected determinants of why countries differ in their levels of productivity and rates of technical progress. Annex 2 augments the analysis reported in the text by extending, for a sub-sample of 48 countries, the period of observation to the year 2000 and using more recently available data series.

As indicated previously, most of the models reported in this paper are estimated by maximum likelihood using the HLM algorithm, and model 6a in Table 3 reports the HLM results. To relate the HLM approach to those more frequently used in economics, models 6b and 6c

[12] Note that adding country indicator variables to the right-hand side of equation (1) along with interaction terms between those indicators and other variables would, from an algebraic perspective, be equivalent to utilization of supplementary equations (3) and (4). Estimation of this data set in this format is unworkable. Edwards (1998) approaches this question in a somewhat different way by first calculating total factor productivity growth using coefficients estimated in a random effects model then using that result as the dependent variable in separate regressions.

Table 3. Determinants of Income Levels: The Effects of Physical Capital, Health, Education, Geography and Technical Progress (53 countries with 316 observations)

Independent Variable	Model 5	6a[a]	6b[a]	6c[a]	7	8
I. Time-invariant determinants of income level:						
constant	8.27	2.23	2.55	2.25	2.96	2.63
	(65.72)	(1.61)	(1.90)	(7.98)	(2.00)	(1.71)
tropics					-0.258	-0.449
					(1.84)	(3.36)
II. Time-varying determinants of income level:						
lkpc		0.40	0.40	0.40	0.38	0.41
		(8.17)	(12.25)	(14.90)	(7.58)	(12.05)
med		0.027	0.014	0.027	0.022	0.035
		(1.33)	(0.79)	(1.81)	(1.16)	(2.61)
lasr		0.465	0.41	0.462	0.38	0.32
		(1.98)	(2.02)	(2.61)	(1.55)	(1.41)
ltfr		-0.53	-0.47	-0.53	-0.49	-0.15
		(4.80)	(6.82)	(8.66)	(4.01)	(2.15)
time (common coefficient assumed for all countries)		-0.008	-0.006	-0.008	-0.006	
		(4.46)	(2.41)	(5.09)	(2.65)	
time (average of country-specific coefficients)						-0.001
						(0.67)
Model Statistics						
Within-country variance reduction[b]		73%			73%	89%
Between-country variance reduction[b]		89%			90%	83%
Number of parameters estimated	3	8			9	11
Deviance[c]	285	-175			-181	-295
Within country R-square			73%	73%		
Between country R-square			88%	89%		

[a] Estimation in Model 6a uses HLM's maximum likelihood algorithm. Models 6b and 6c are the equivalent specifications in STATA, cross-sectional time-series regression, using generalized-least-squares. Model 6b shows the fixed-effect results and Model 6c has the random-effect results.

[b] The variance reduction numbers indicate the percentage of the between- or within-country variance found in Model 5 that is explained with the indicated model. Based on Model 5, 8% of the variance in the dependent variable is within-country and 92% is between-country.

[c] "Deviance" is twice the negative log-liklihood value associated with the maximum likelihood parameter estimates. The larger the deviance, the poorer the fit.

Table 4. Determinants of Income Levels and Rates of Technical Progress
(53 countries with 316 observations)

Independent Variable	Model 9	10	11	12	13
I. Time-invariant determinants of income level:					
constant	2.19	1.55	1.37	4.67	20.07
	(1.38)	(0.98)	(0.83)	(16.65)	5.15
tropics	-0.46	-0.39	-0.41	-0.40	-0.32
	(3.59)	(3.26)	(3.10)	(3.32)	(2.49)
II. Time-varying determinants of income level:					
lkpc	0.41	0.38	0.40	0.40	-2.06
	(12.45)	(11.86)	(12.64)	(13.39)	3.85
med	0.03	0.04		0.04	0.03
	(2.56)	(2.90)		(3.00)	(2.33)
lasr	0.38	0.50	0.55		-2.40
	(1.63)	(2.13)	(2.21)		(3.95)
ltfr	-0.10	-0.04	-0.09	-0.04	-0.11
	(1.58)	(0.78)	(1.66)	(0.79)	(1.79)
lkpc * lasr					0.38
					(4.65)
III. Determinants of technical progress:					
constant (common across countries)	-0.008	-0.012	-0.014	-0.051	-0.005
	(2.28)	(3.83)	(3.45)	(0.96)	(2.16)
coastal	0.013	0.009	0.007	0.007	
	(2.93)	(2.40)	(2.22)	(1.73)	
open6590		0.017	0.014	0.016	
		(5.97)	(4.71)	(5.01)	
med65			0.001		
			(1.98)		
lasr65				0.006	
				(0.76)	
Model Statistics					
Within-country variance reduction[a]	89%	90%	89%	90%	89%
Between-country variance reduction[a]	83%	83%	82%	81%	86%
Number of parameters estimated	12	13	13	13	12
Deviance[b]	-305	-329	-323	-324	-313

[a] The variance reduction numbers indicate the percentage of the between- or within-country variance found in Model 5 that is explained with the indicated model. Based on Model 5, 8% of the variance in the dependent variable is within-country and 92% is between-country.

[b] "Deviance" is twice the negative log-liklihood value associated with the maximum likelihood parameter estimates. The larger the deviance, the poorer the fit.

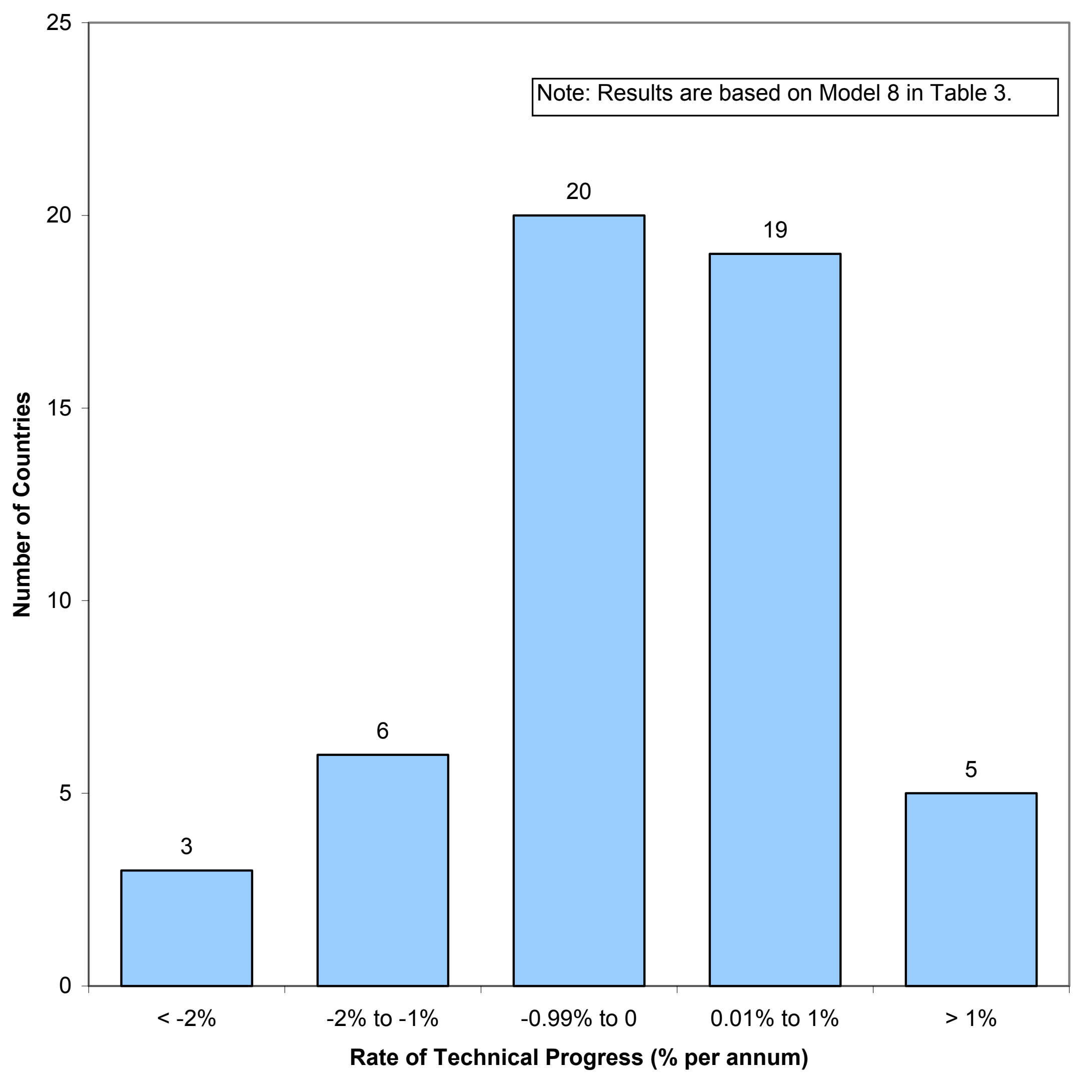
convey results from using fixed effects (6b) and random effects (6c) models with the same specifications. These are estimated with generalized least squares (GLS) using the STATA package. These basic models follow much of the literature in maintaining the assumption that technical progress proceeds at the same rate across all countries (i.e. there is a single coefficient on **time**). In these models, estimated technical progress is actually negative – with a magnitude of around -0.8% per annum – suggesting strongly an underlying heterogeneity [given, for example, the finding of Boskin and Lau (2000) concerning the central (positive) role of technical progress in explaining growth in the G-5 economies]. The HLM algorithm for computing standard errors of estimates of coefficients generally results in larger values than does GLS hence the reported t-ratios are smaller in model 6a than in the other two. Estimated coefficients, however, are virtually the same in all three models as would be expected. The elasticity of output with respect to physical capital is 0.40 with a tiny standard error; this remains virtually unchanged in all our specifications, included those reported in Annex 2. The elasticity with respect to the adult male survival rate or **asr** is about 0.45, which is statistically significant but only marginally so.

Models 7 and 8 add the geographical variable **tropics** and return to HLM with its maximum likelihood estimation procedure. Model 7 continues to maintain the assumption that the rate of technical progress is constant across countries whereas model 8 relaxes that assumption. Model 8 achieves a markedly better overall fit to the data (the deviance value drops from –181 to –298), and its better overall explanatory power has the effect of changing the (now *average*) rate of technical progress almost to zero, which is consistent with findings of Kim and Lau (1996) for East Asian Countries. Figure 1 illustrates the huge variation across countries in the rate of technical progress (or diffusion) as estimated from model 8 and underscores the importance of treating technical progress as a country-specific variable. Note that in model 8 the estimated effects of **asr** and **tfr** are much reduced from models 6a and 7. The further exploration of sources of technical progress reported in Table 4 continues to suggest that the adverse effect of a high **tfr** on income levels is modest, but an important health effect reappears and is robust with respect to alternative specifications.

Models 9 through 13 in Table 4 convey our main results. Results for each model are divided into three categories: time-invariant determinants of income level, time-varying determinants of income level and determinants of the country-specific rate of technical progress. The time-invariant determinants of income level consist of: an intercept term that is common to all countries (γ_{00} in equation 3); an effect due to **tropics** i.e. a measure of the extent to which being tropical affects the level of a country's income; and a third country-specific "fixed" effect (μ_{0i} in equation 3) that is not reported in Table 4. Being fully in the tropics (**tropics** = 1) is estimated to result in a downward shift in income *level* of between 27% and 37%, depending on the model, relative to an otherwise similar country from entirely outside the tropics. As previously noted, we found the variable **coastal** to have its effects only through technical progress

Figure 1:

Country-specific Variation in the Annual Rate of Technical Progress



whereas **tropics** has no estimated effect on technical progress but only the effect on income level reported here.[13]

The next category of determinants consists of time-varying ones for each country – levels of health, fertility, education and physical capital. The coefficients are to be interpreted in the standard way, e.g. in models 9 through 12 the elasticity of income level with respect to physical capital stock is found to be about 0.4.[14] Models 9 - 12 vary in how they model the determinants of technical progress. Model 13 explores the possibility of interaction between the health of a population and physical capital levels. The findings are of a strong interaction and one that has the effect of markedly increasing the estimated impact of health on income. Model 13 is on the whole less satisfactory in terms of fit than our other models, and we report it principally to pose questions for further analysis. It does suggest that our estimates of the contribution of health improvements to economic growth, reported in the final section, are likely to be conservative.

The third block of coefficients in Table 4 shows our estimates of the effects of several factors likely to be influencing the rate of technical progress (or diffusion). Model 9 reports on a single determinant, **coastal**, and model 10 adds **open6590** as an additional determining variable. Inclusion of **open6590** reduces the estimated effect of **coastal** by about 30% but **coastal** nonetheless remains quantitatively important and statistically significant. Model 11 retains both these variables but changes how education is modeled by including initial education level, **med65**, as a determinant of technical progress rather than having **med** be a time-varying determinant of income as in models 9 and 10.[15] Each of these three variables is, in different ways, capturing an element of contact with the outside world. Coastal nations' access to ocean trade greatly reduces the cost and ease of commerce (Radelet, Sachs and Lee, 1997). Open economic policies likewise facilitate knowledge transfer, allow realization of comparative advantage and create competitive pressures for innovation. More educated populations, as Schultz (1993, chapter 3) and others have stressed, enjoy economic advantage at least as much from their ability to adapt to change (deal with 'disequilibria') as from simply producing more from a given

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[13] Models in literature, like those reported in Table 2, by the nature of their specification *assume* that **tropics** has its effect on the growth rate rather than level of income. The coefficients in Table 2, Models 2 and 4, suggest that tropical location reduces growth rates by between 1% and 2% per annum, i.e. those models imply a smaller short-term effect of being in the tropics and a larger long-term effect than what we estimate. When growth rate prediction models specify convergence to a long-term (country-specific) steady state, however, the long-term estimated effect of **tropics** is not greatly different than our estimate. For example, Radelet, Sachs and Lee (1997, p.14) find a 47% reduction in steady state income from being tropical relative to our finding of a 27-37% reduction. Hall and Jones (1999) find 'distance from the equator' to be their strongest predictor of long-term economic success, and that the adverse effect of an equatorial location to be much stronger than our findings suggest.

[14] We explored whether the physical capital elasticity was related to initial levels of physical capital and concluded that this was unlikely.

[15] The relatively slow change over time within a country of **med** suggests the plausibility of modeling it either way. Over the 25 years considered here, the dynamic effect of education (model 11) would have less effect on end-of-period income than would modeling its effect on levels (models 9 or 10). Over a longer time period, however, if education did indeed affect technical progress, the effect through technical progress would be more significant. (Model 11 could also be modified to include both initial level of education, **med65**, and its average level over subsequent years as determinants of the rate of technical progress.) Temple (1999) has noted that in many circumstances there will be little quantitative difference in results resulting from modeling levels or growth rates. This would appear to be the case with **med**.

input list. Models 9 to 12 strongly suggest that the gains from contact with the world are indeed dynamic ones, involving as they do quantitatively important driving forces for technical change.

For our purposes in the remainder of this paper we will focus on model 10, which leaves education as a time-varying determinant of income level. Our results concerning health are insensitive to this choice although an analysis concerned with the long-term effects of education might choose to focus on model 11. In contrast to the case with education, our explanation of alternative specifications (e.g. model 12) suggests that the effect of health is on *levels* of income. To put this slightly differently, while education can potentially be viewed as a (weak) endogenous source of technical progress, health's effects do not appear to be through this mechanism.

In model 10, a country's rate of technical progress is determined from an element that is common across countries (-0.012 or γ_{10} from equation 4), from how coastal and open it is by way of the relevant coefficients on those variables and by a remaining country-specific effect (μ_{1i} from equation 4). The important point to note about determinants of technical progress is how strong are the effects both of being coastal and of having open economic policies. Other things equal, an inland Bolivia would have an annual rate of technical progress 0.9% less per annum than, say, a highly coastal Jamaica. At least some component of technical progress is, clearly, best viewed as exogenous.[16]

The difference between fully closed and fully open trade policies is even more substantial – about 1.7% per year (in model 10)[17]. While the OLS regressions predicting growth rates reported in Table 2 show an even more substantial effect of open policies on growth, it needs to be remembered that those models fail to distinguish between level effects and growth rate effects, and in particular they assume all effects are on growth. Such models (e.g. Romer, 1989; Sachs and Warner, 1997) are therefore incapable of ascribing the estimated coefficients unequivocally to growth effects but are nonetheless valuable in identifying main effects. Our empirical analysis concludes that technical progress includes a substantial endogenous component with respect to policies on economic openness. (Important parts of the residual country-specific element of technical progress may also, of course, be endogenous.)

Of all the time-varying determinants of income in model 10 only **tfr** has an estimated impact that is statistically insignificant, although in some of the other models its coefficient is notably larger and significant. Allowing technical progress to be country-specific seems to be capturing some of the effects of **tfr** . That said, given the magnitude of fertility decline in many countries during the period being analyzed, even the small coefficient can still lead to explanation of a noticeable amount of a country's growth between 1965 and 1990.

Annex 2 reports results from a specification equivalent to model 10 but which uses data at 10 year intervals for the period 1960 to 2000 (and data drawn from somewhat more recent sources). For the most part the Annex 2 results confirm the findings from model 10 that we have just discussed. The exceptions are:

[16] Easterly and Levine (1997) have found strong (adverse) effects of ethnolinguistic diversity on both the level and the growth rate of income. This would be another potential exogenous determinant of technical change and another example of how factors impeding economic interactions (with either the rest of a country or the outside world) could adversely affect the rate of technical progress.

[17] Frankel and Romer (1999, pp. 390-91) use geographical instruments to assess directly the impact of the share of trade in national income to productivity change. They find strong effects.

(i) the estimated magnitude of the adverse effect of being in the tropics on level of output is reduced to 25% of its level with the original data set and becomes insignificant,

(ii) the estimated effects of health and of education are reduced, and the health variable switches to insignificant,

(iii) the estimated effects of physical capital and total fertility rates become more substantial, and

(iv) the effects on technical progress of being coastal and of economic openness become less substantial (which remaining highly statistically significant).

Finally, we make that Annex 2 also reports the results of estimating model 13 – with the interaction term between physical capital and adult survival. The calculated elasticity of output with respect to adult survival in model 13 is about 0.7 , substantially higher than in model 10. It remains this high with parameters estimated from the augmented data set.

5. Conclusion: Health and Economic Openness as Sources of Growth

One purpose of this paper was to examine health's contribution to economic growth and, for that reason, using model 10, we assessed how much economic growth between 1965 and 1990 that could be attributed to changes in health. The average adult survival rate increased from 707 per thousand in 1965 to 796 in 1990. The estimated resulting increase in the level of 1990 income then implies, on average, a contribution of 0.23% per year from better health to the income growth rate during this period. This was about 11% of growth overall. Annex Table 1.2 reports the results for the countries we analyzed along with basic data on each country's income growth rates and adult male survival rates.

Countries with initially high levels of **asr** typically realized a much more modest contribution to their growth rates from health improvements than did countries with an initially lower initial **asr**. In these countries **asr** improvements resulted in gains in growth rates estimated at 0.1% per annum or less. In Honduras, Bolivia and Thailand, to take examples of a more major effect, health improvements added about half a percent to the annual per capita income growth. This finding of diminishing returns is consistent with that of Bhargava et al (2001) but should be interpreted with some caution for several reasons. First, lack of data on morbidity or disability required use of mortality rates as a proxy for overall health conditions, but it is plausible that morbidity declines may be significant for income growth, only partially correlated with mortality decline and, in particular, that they might lag mortality decline. Second, health improvements above age 60 are likely to be important (in terms, for example, of age of retirement) and may show scope for significant improvement well after **asr** has reached near-maximum levels (in the low 900s). The instrumental value of health improvements for income growth probably is, as our analysis concludes, limited by (very slowly changing) upper bounds on health. But the limit is probably not reached quite as rapidly as our data, taken literally, would suggest.

The major purpose of this paper was to estimate empirically the difference across countries in their rates of technical progress and to explore some potential determinants of this variation. In particular we explored health among other potential endogenous sources of technical progress and concluded that health's effects on outcomes were unlikely to be through this mechanism.

Education's effects, in contrast, were plausibly in part through technical progress but the magnitude of that effect was small. Policies of economic openness, in contrast, were found to have a major impact on the rate of technical progress.[18] Many of our parameters are estimated with only modest precision, and alternative models could be defended. Yet no variants of our models failed to show major differences across countries in rates of technical progress and that openness of the economy was a powerful predictor of these differences.

Annex Table 1.3 reports results of a decomposition of growth into its constituents for 47 of the countries in our sample (using model 10 of Table 4). The final two columns show the effect of technical progress overall and of the component of technical progress due to economic openness. On average, for the countries in our sample, for the period 1965-90, technical progress was positive, but only slightly so, and accounted for only 4.5% of all growth. This low total for technical progress comprised, however, a strong positive component due to actual openness (relative to none) counterbalanced by a negative component due to everything else. The average value of **open6590** was 0.5 and its coefficient in model 10 is 0.017 implying about a 0.85% increment in the annual rate of technical progress for the average country relative to a closed country. This results in openness being responsible for about 37% of the observed average growth rate of 2.3% per annum.

Country-specific decompositions should be viewed only as suggestive, but they do give a broad picture of the importance of alternative sources of growth. Increases in physical capital stocks dominate (accounting for 67% of total growth) but both education improvements (14%) and health improvements (11%) are important, and relatively much more so in some countries.[19]

Our findings point to the importance of investment – in physical capital, education and health – for affecting economic outcome levels in the medium term. They point to the importance of economic openness for increasing the rates of technical progress. Understanding reasons why, for much of the world, technical progress (after controlling for economic openness) is negative is a major challenge posed by our research.

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[18] The economic openness variable no doubt proxies for other aspects of the economic policy in addition to international openness *per se*. Indeed Hall and Jones (1997) use this variable as one of two componenets of their construct social infrastructure.

[19] Boskin and Lau (2000) and Dougherty and Jorgenson (1996), in decompositions for the G-5 countries, found technical progress followed by physical capital accumulation to be principal sources of growth. The average contribution of technical progress reported for the G-7 countries in Annex Table 1.3 is 22% of total per capita income growth – far above the 4.5% for the sample as a whole but substantially less than estimated by Boskin and Lau or Dougherty and Jorgenson. This results from several factors (in addition to the possibility of differences resulting from somewhat differently constructed data sets). One is that Boskin-Lau separate out a negative effect due to the oil price shock of the early 1970s that, if not separated out, would have reduced their estimates of the contribution of technical progress. Second, and probably more important, their more powerful estimation procedures allow them to identify technical progress as capital-augmenting and it is likely that our estimates of a high proportion of growth due to physical capital investments embodies part of what they are able to attribute to capital-augmenting technical change.

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Annex 1: Supplementary Tables

Annex Table 1.1: Initial and Terminal Values of Country Data

Annex Table 1.2: The Contribution of Improvements in Adult Male Survival Rates to Economic Growth, 1965-90

Annex Table 1.3: Sources of Economic Growth in 47 Countries, 1965-90

Annex Table 1.1: Initial and Terminal Values of Country Data

NAME	YEAR	YPC	KPC	MED	ASR	TFR	TROPICS	COASTAL	OPEN6590
Argentina	1965	5,018	2,175	5.58	788	3.07	0.03	0.20	0.00
Argentina	1990	4,706	3,947	8.08	812	2.89	0.03	0.20	0.00
Australia	1965	8,823	8,409	9.30	791	2.98	0.39	0.20	1.00
Australia	1990	14,445	18,039	10.69	865	1.88	0.39	0.20	1.00
Austria	1965	6,144	3,636	4.67	779	2.69	0.00	0.62	1.00
Austria	1990	12,695	16,433	8.09	856	1.45	0.00	0.62	1.00
Belgium	1965	6,749	5,807	8.23	803	2.61	0.00	0.99	1.00
Belgium	1990	13,232	15,282	9.16	859	1.62	0.00	0.99	1.00
Bolivia	1965	1,346	898	5.96	549	6.60	1.00	0.02	0.77
Bolivia	1990	1,658	1,785	5.60	693	4.90	1.00	0.02	0.77
Botswana	1965	574	99	1.73	501	6.90	0.70	0.00	0.42
Botswana	1985	2,337	1,592	3.37	769	6.03	0.70	0.42	0.00
Canada	1965	8,664	7,177	9.66	820	3.12	0.00	0.05	1.00
Canada	1990	17,173	21,351	10.44	872	1.83	0.00	0.05	1.00
Chile	1965	3,264	1,625	5.25	771	4.86	0.16	0.68	0.58
Chile	1990	4,338	3,492	6.76	825	2.62	0.16	0.68	0.58
Colombia	1965	1,816	2,076	3.25	727	6.52	1.00	0.28	0.19
Colombia	1990	3,300	4,130	4.27	778	3.10	1.00	0.28	0.19
Denmark	1965	8,436	6,647	10.05	843	2.61	0.00	1.00	1.00
Denmark	1990	13,909	18,451	10.98	845	1.67	0.00	1.00	1.00
Dominican Rep.	1965	1,271	456	2.67	707	7.00	1.00	1.00	0.00
Dominican Rep.	1990	2,166	1,891	4.42	843	3.30	1.00	1.00	0.00
Ecuador	1965	1,591	1,891	3.55	725	6.80	1.00	0.38	0.69
Ecuador	1990	2,755	4,885	5.95	817	3.65	1.00	0.38	0.69
Finland	1965	6,514	7,926	7.63	742	2.40	0.00	0.29	1.00
Finland	1990	14,059	23,526	9.70	827	1.78	0.00	0.29	1.00
France	1965	7,304	5,272	4.98	797	2.83	0.00	0.85	1.00
France	1990	13,904	16,305	7.02	859	1.78	0.00	0.85	1.00
Germany	1965	7,912	6,939	7.98	790	2.50	0.00	0.94	1.00
Germany	1990	14,341	24,356	8.91	845	1.45	0.00	0.94	1.00
Greece	1965	3,067	2,610	6.23	835	2.30	0.00	0.93	1.00
Greece	1990	6,768	8,968	9.20	883	1.40	0.00	0.93	1.00
Guatemala	1965	1,781	653	1.74	534	6.73	1.00	0.42	0.12
Guatemala	1990	2,127	1,043	3.41	736	5.57	1.00	0.42	0.12
Honduras	1965	1,121	836	2.18	626	7.39	1.00	0.67	0.00
Honduras	1990	1,377	1,275	5.02	798	5.25	1.00	0.67	0.00
Hong Kong	1965	3,492	3,614	7.47	725	4.66	1.00	1.00	1.00
Hong Kong	1990	14,849	8,302	9.77	878	1.33	1.00	1.00	1.00
India	1965	751	329	2.95	639	6.28	0.51	0.25	0.00
India	1990	1,264	760	5.40	764	3.80	0.51	0.25	0.00
Iran	1965	3,364	788	1.87	788	7.12	0.00	0.10	0.00
Iran	1990	3,392	4,626	4.73	830	5.63	0.00	0.10	0.00
Ireland	1965	4,000	2,684	6.35	821	4.03	0.00	0.91	0.96
Ireland	1990	9,274	8,350	8.02	847	2.12	0.00	0.91	0.96

Annex Table 1.1: Continued.

NAME	YEAR	YPC	KPC	MED	ASR	TFR	TROPICS	COASTAL	OPEN6590
Israel	1965	4,644	4,427	7.58	852	3.82	0.00	0.92	0.23
Israel	1990	9,298	8,388	9.61	879	2.81	0.00	0.92	0.23
Italy	1965	5,691	4,844	5.37	834	2.67	0.00	0.86	1.00
Italy	1990	12,488	12,830	6.90	874	1.26	0.00	0.86	1.00
Jamaica	1965	2,104	1,396	2.72	770	5.71	1.00	1.00	0.38
Jamaica	1990	2,545	1,717	4.36	845	2.85	1.00	1.00	0.38
Japan	1965	4,491	3,229	7.94	789	2.10	0.00	0.94	1.00
Japan	1990	14,331	23,108	8.96	892	1.54	0.00	0.94	1.00
Kenya	1965	614	483	2.40	493	8.12	1.00	0.08	0.12
Kenya	1990	911	444	4.55	643	5.75	1.00	0.08	0.12
Korea, Rep. of	1965	1,058	725	6.60	601	4.96	0.00	0.89	0.88
Korea, Rep. of	1990	6,673	7,495	10.85	761	1.78	0.00	0.89	0.88
Malawi	1965	412	50	2.86	499	7.75	1.00	0.00	0.00
Malawi	1990	519	183	3.41	521	7.17	1.00	0.00	0.00
Mauritius	1965	3,136	965	4.31	709	4.99	1.00	1.00	1.00
Mauritius	1990	5,838	2,201	6.19	759	2.05	1.00	1.00	1.00
Mexico	1965	3,351	1,771	3.13	728	6.73	0.47	0.37	0.19
Mexico	1990	5,827	4,419	7.04	827	3.46	0.47	0.37	0.19
Nepal	1965	650	81	0.30	488	6.02	0.00	0.00	0.00
Nepal	1985	936	316	2.06	640	6.06	0.00	0.00	0.00
Netherlands	1965	7,396	5,294	5.73	844	3.04	0.00	1.00	1.00
Netherlands	1990	13,029	13,504	8.97	870	1.62	0.00	1.00	1.00
New Zealand	1965	9,032	6,967	9.83	804	3.73	0.00	0.96	0.19
New Zealand	1990	11,513	14,986	11.57	853	2.18	0.00	0.96	0.19
Norway	1965	6,950	15,185	5.60	851	2.93	0.00	0.48	1.00
Norway	1990	14,902	24,525	8.28	866	1.93	0.00	0.48	1.00
Paraguay	1965	1,277	67	3.89	787	6.60	0.56	0.32	0.08
Paraguay	1990	2,128	304	5.21	831	4.50	0.56	0.32	0.08
Peru	1965	2,501	1,989	3.98	636	6.71	1.00	0.24	0.12
Peru	1990	2,188	2,811	6.54	772	3.55	1.00	0.24	0.12
Philippines	1965	1,243	959	4.72	598	6.82	1.00	1.00	0.12
Philippines	1990	1,763	1,363	6.91	727	4.07	1.00	1.00	0.12
Portugal	1965	2,407	1,317	2.95	799	3.08	0.00	0.69	1.00
Portugal	1990	7,478	5,312	4.34	823	1.51	0.00	0.69	1.00
Sierra Leone	1965	1,114	28	1.04	431	6.34	1.00	0.49	0.00
Sierra Leone	1990	901	81	2.89	399	6.50	1.00	0.49	0.00
Spain	1965	4,580	2,175	3.54	851	2.94	0.00	0.46	1.00
Spain	1990	9,583	9,923	6.99	866	1.33	0.00	0.46	1.00
Sri Lanka	1965	1,179	1,473	4.65	799	4.92	1.00	0.99	0.23
Sri Lanka	1990	2,096	3,262	6.34	816	2.54	1.00	0.99	0.23
Sweden	1965	9,402	7,122	8.35	855	2.39	0.00	0.30	1.00
Sweden	1990	14,762	20,492	9.61	881	2.13	0.00	0.30	1.00
Switzerland	1965	11,150	14,471	7.19	817	2.57	0.00	0.33	1.00
Switzerland	1990	16,505	36,951	9.65	872	1.59	0.00	0.33	1.00

Annex Table 1.1: Continued.

NAME	YEAR	YPC	KPC	MED	ASR	TFR	TROPICS	COASTAL	OPEN6590
Syrian Arab Rep.	1965	2,011	2,557	2.69	648	7.63	0.00	0.14	0.04
Syrian Arab Rep.	1990	3,897	3,682	6.26	763	6.28	0.00	0.14	0.04
Thailand	1965	1,136	488	4.48	644	6.28	1.00	0.28	1.00
Thailand	1990	3,580	2,604	5.90	793	2.34	1.00	0.28	1.00
Turkey	1965	1,812	1,138	3.15	831	5.87	0.00	0.39	0.08
Turkey	1990	3,741	3,289	4.51	835	3.56	0.00	0.39	0.08
United Kingdom	1965	7,679	4,033	7.24	800	2.86	0.00	1.00	1.00
United Kingdom	1990	13,217	10,462	8.79	861	1.83	0.00	1.00	1.00
United States	1965	11,649	7,270	9.02	784	2.91	0.00	0.26	1.00
United States	1990	18,054	17,040	11.97	851	2.08	0.00	0.26	1.00
Venezuela	1965	7,512	4,391	3.29	752	6.18	1.00	0.56	0.08
Venezuela	1990	6,055	6,349	4.92	814	3.48	1.00	0.56	0.08
Yugoslavia	1965	2,407	1,109	6.03	835	2.50	0.00	0.63	0.00
Yugoslavia	1990	4,548	3,891	7.97	832	2.17	0.00	0.63	0.00
Zambia	1965	1,110	833	4.11	431	6.64	1.00	0.00	0.00
Zambia	1990	689	451	5.93	566	6.24	1.00	0.00	0.00
Zimbabwe	1965	946	2,410	2.30	483	8.00	1.00	0.00	0.00
Zimbabwe	1990	1,182	1,854	4.16	695	4.85	1.00	0.00	0.00

Annex Table 1.2: The Contribution of Improvements in Adult Male Survival Rates to Economic Growth, 1965-90

Country	Adult Male Survival Rate (**asr**)[a] 1965	1990	% Increase	Contribution of **asr** change to the annual rate of per capita gdp growth
Total Sample	**707**	**796**	**12%**	**0.23%**
(53 countries)				
ARGENTINA	788	812	3.0%	0.06%
AUSTRALIA	791	865	9.4	0.18
AUSTRIA	779	856	10	0.19
BELGIUM	803	859	7.0	0.13
BOLIVIA	549	693	26	0.46
BOTSWANA (1965-85)	*501*	*769*	*53*	*1.07*
CANADA	820	872	6.3	0.12
CHILE	771	825	7.0	0.14
COLOMBIA	727	778	7.0	0.14
DENMARK	843	845	0.2	0.00
DOMINICAN REP.	707	843	19	0.35
ECUADOR	725	817	13	0.24
FINLAND	742	827	11	0.22
FRANCE	797	859	7.8	0.15
GERMANY	790	845	7.0	0.13
GREECE	835	883	5.7	0.11
GUATEMALA	534	736	38	0.64
HONDURAS	626	798	27	0.48
HONG KONG	725	878	21	0.38
INDIA	639	764	20	0.36
IRAN, ISLAMIC REP. OF	788	830	5.3	0.10
IRELAND	821	847	3.2	0.06
ISRAEL	852	879	3.2	0.06
ITALY	834	874	4.8	0.09
JAMAICA	770	845	10	0.19
JAPAN	789	892	13	0.24
KENYA	493	643	30	0.53
KOREA, REP. OF	601	761	27	0.47
MALAWI	499	521	4.4	0.09
MAURITIUS	709	759	7.1	0.14
MEXICO	728	827	14	0.25
NEPAL (1965-85)	*488*	*640*	*31%*	*0.68%*
NETHERLANDS	844	870	3.1	0.06
NEW ZEALAND	804	853	6.1	0.12
NORWAY	851	866	1.8	0.03
PARAGUAY	787	831	5.6	0.11
PERU	636	772	21	0.39
PHILIPPINES	598	727	22	0.39
PORTUGAL	799	823	3.0	0.06
SIERRA LEONE	431	399	-7.4	-0.15
SPAIN	851	866	1.8	0.03
SRI LANKA	799	816	2.1	0.04
SWEDEN	855	881	3.0	0.06
SWITZERLAND	817	872	6.7	0.13
SYRIAN ARAB REP.	648	763	18	0.33
THAILAND	644	793	23	0.42
TURKEY	831	835	0.5	0.01
UNITED KINGDOM	800	861	7.6	0.15
UNITED STATES OF AMERICA	784	851	8.5	0.16
VENEZUELA	752	814	8.2	0.16
YUGOSLAVIA, FED. REP	835	832	-0.4	-0.01
ZAMBIA	431	566	31	0.54
ZIMBABWE	483	695	44	0.73

[a] The adult survival rate (**asr**) is defined as the probability of surviving to the 60th birthday given the person is alive at age 15, expressed per thousand.

Annex Table 1.3: Sources of Economic Growth in 47 Countries, 1965-90

Country	Annual growth rate of per capita income	**Sources of Growth (% of total)**						
		Change in				Technical progress		
		physical capital	education	health	fertility	Total	(due to 'openness')	
SAMPLE of 47 countries [a]	**2.3%**	**67.1%**	**13.9%**	**10.7%**	**3.8%**	**4.5%**	**(+37%)**	
AUSTRALIA	2.0%	54.5%	9.6%	8.4%	3.7%	23.7%	77.8%	1
AUSTRIA	2.90	70.9	15.6	5.8	3.3	4.4	(51.2)	2
BELGIUM	2.69	50.7	4.7	4.6	2.8	37.1	(57.0)	3
BOLIVIA	0.83	137.2	-7.0	61.0	6.7	-97.9	(167.3)	4
BOTSWANA (1965-85)	7.02	79.3	4.5	16.1	0.4	-0.4	(13.1)	5
CANADA	2.74	54.6	3.8	4.0	3.0	34.6	(54.5)	6
CHILE	1.14	77.8	14.9	9.0	7.1	-8.8	(64.2)	7
COLOMBIA	2.39	47.5	6.8	6.1	5.8	33.7	(14.3)	8
DENMARK	2.00	61.6	5.4	0.2	3.0	29.7	(65.7)	9
DOMINICAN REP.	2.13	90.7	10.8	14.7	5.4	-21.7	(0.0)	10
ECUADOR	2.20	60.9	14.9	10.1	4.5	9.7	(48.2)	11
FINLAND	3.08	53.5	9.9	7.0	1.7	28.0	(53.5)	12
FRANCE	2.58	63.8	11.2	5.6	3.0	16.5	(61.5)	13
GERMANY	2.38	73.5	5.3	5.2	3.6	12.5	(63.7)	14
GREECE	3.17	57.1	13.3	3.4	2.6	23.6	(50.4)	15
GUATEMALA	0.71	148.7	51.4	133.7	6.8	-240.6	(41.5)	16
HONDURAS	0.82	63.3	41.3	47.7	5.8	-58.1	(0.0)	17
HONG KONG	5.79	22.1	5.9	6.7	3.7	61.6	(28.9)	18
INDIA	2.08	67.3	19.1	18.8	4.5	-9.8	(0.0)	19
IRELAND	3.36	53.1	7.6	1.9	3.4	34.0	(48.9)	20
ISRAEL	2.78	38.7	11.9	2.5	2.1	44.8	(15.2)	21
ITALY	3.14	47.6	7.2	3.0	4.1	38.1	(53.1)	22
JAMAICA	0.76	36.7	28.2	21.6	13.9	-0.4	(73.4)	23
JAPAN	4.64	67.6	3.4	5.5	1.2	22.3	(37.4)	24
KENYA	1.58	-8.7	21.6	36.1	4.0	47.0	(13.5)	25
KOREA, REP. OF	7.37	48.8	8.6	6.5	2.4	33.7	(20.0)	26
MALAWI	0.92	239.4	9.8	10.4	1.6	-161.3	(0.0)	27
MAURITIUS	2.49	39.9	8.8	4.3	4.8	42.2	(52.6)	28
MEXICO	2.21	56.1	23.3	10.3	4.6	5.8	(12.7)	29
NEPAL (1965-85)	1.82	129.8	16.3	33.9	-0.1	-79.9	(0.0)	30
NETHERLANDS	2.26	53.7	18.0	2.3	4.1	22.0	(62.4)	31
NEW ZEALAND	0.97	88.6	19.5	9.0	7.0	-24.1	(23.9)	32
NORWAY	3.05	21.2	11.5	1.0	2.1	64.2	(48.1)	33
PARAGUAY	2.04	104.8	8.9	4.9	3.0	-21.7	(6.0)	34
PHILIPPINES	1.40	41.0	24.8	29.9	6.8	-2.6	(15.2)	35
PORTUGAL	4.53	48.9	4.7	1.4	2.8	42.2	(38.2)	36
SPAIN	2.95	80.3	17.7	1.2	4.7	-3.9	(57.6)	37
SRI LANKA	2.30	43.3	8.9	1.5	4.1	42.2	(13.6)	38
SWEDEN	1.80	78.6	9.1	2.9	1.0	8.4	(81.0)	39
SWITZERLAND	1.57	86.8	22.1	7.9	5.0	-21.8	(100.7)	40
SYRIAN ARAB REP.	2.65	22.8	21.7	13.4	1.4	40.7	(2.7)	41
THAILAND	4.59	57.9	4.8	9.4	3.8	24.1	(37.6)	42
TURKEY	2.90	69.7	8.7	0.4	3.7	17.5	(5.7)	43
UNITED KINGDOM	2.17	59.1	9.3	6.0	3.1	22.5	(67.5)	44
AMERICA	1.75	62.7	21.0	7.9	2.8	5.6	(80.1)	45
REP	2.55	76.2	11.4	-0.3	1.0	11.7	(0.0)	47
ZIMBABWE	0.89	-61.7	42.4	112.4	13.3	-6.3	(0.0)	48

a Five of the 53 countries in our sample experienced negative growth in per capita income during the period and one (Iran) had zero growth. We did not attempt growth decomposition for these countries.

Annex 2: Updating the Analysis to the Year 2000

In order to update the findings, we constructed a new dataset that covers the time period of between 1960 and 2000. We made the following changes to our existing data in both sources and data definition:

1. For the income per capita and physical per capita variables[i], we used revised numbers from the Penn World Tables 6.1 (Heston, Summer & Aten, 2002) to replace the Penn World Table 5.6 values (Heston & Summers, 1996). Another change on these two variables is that we used real GDP per capita in 1996 international dollars (Laspeyres series) instead of real GDP per capita in 1985 international dollars (chain series) numbers we previously used. It was done to calculate compatible physical capital per capita values with the existing version 6.1 variables.
2. The health variables are extracted from the World Development Indicators from the World Bank (2002).
3. For the education variable, instead of using Barro-Lee's (1996) total number of years of education for the male population aged 15 and over, we used Cohen & Soto's (2001) education numbers for the population between age 15 and 64. The variable is at 10-year intervals from 1960 to 2000, which gives us only 5 observations per country rather than the 6 that we have with Barro & Lee.

The descriptive information of this newly constructed data is reported in Annex Table 2.1. As indicated there, this new data consist of 48 out of the 53 countries that are in our original data. (Botswana, Hong Kong, Israel, Sri Lanka, and Yugoslavia are excluded from the analysis reported in Annex Tables 2.1 and 2.2 due to missing values.)

Annex Table 2.2 reports the HLM results repeating the analysis for model 10 and 13 using this newly constructed data. The original models 10 and 13 results, from Table 4, are also reported there for comparison. Based on this new data of 48 countries, we found that our existing models with the new data set we are getting broadly similar patterns of findings although, obviously, there are some changes in the magnitude of coefficients, as discussed at the end of section IV in the text.

[i] KPC is calculated from YPC and the investment ratio from the Penn World Tables 6.1, using a perpetual inventory approach. The specific calculation for KPC is as follows. For the first year that data was available, a starting capital stock was estimated as (first year GDP * average investment ratio for the first five years) / (assumed depreciation rate). The first available year varied by country but was typically 1950 or 1960. We used a depreciation rate of 7%. Subsequent years' capital stock estimates were calculated as prior year capital stock + investment – depreciation.

Annex Table 2.1. Variable Definitions, Means and Standard Deviations, Overall and for 1960 and 2000 (48 countries)

Variable	Defintions	Overall Mean	Overall Std. Dev.	1960 Mean	1960 Std. Dev.	2000 Mean	2000 Std. Dev.
Time-varying Variables							
ypc	income per capita, in 1996 international dollars (in LASPEYRES series)	9,266	7,666	5,156	3,832	13,426	9,947
kpc	physical capital per capita, in 1996 international dollars (in LASPEYRES series)[a]	21,146	20,932	11,466	10,113	31,113	27,398
ed	average education of the population between age 15 and 64	7.3	3.3	5.4	2.9	9.0	2.9
asr	adult survival rate, per thousand (for males)[b]	758.8	123.1	702.0	133.2	800.9	138.7
tfr	total fertility rate[c]	3.7	1.9	4.9	2.0	2.5	1.2
time	year of observation minus 1960	20.3	14.1	0.0	0.0	40.0	0.0
lypc	natural logarithm of **ypc**	8.70	1.03	8.21	0.90	9.09	1.05
lkpc	natural logarithm of **kpc**	9.27	1.36	8.82	1.19	9.69	1.37
lasr	natural logarithm of **asr**	6.62	0.19	6.53	0.21	6.66	0.23
ltfr	natural logarithm of **tfr**	1.15	0.54	1.49	0.45	0.83	0.43
	number of available observations (overall or indicated time period)	**230**		**44**		**47**	
Time-invariant Variables							
tropics	fraction of the country's land area situated in the geographical tropics	0.40	0.47	0.40	0.47	0.40	0.47
coastal	fraction of the country's land area located within waterway	0.52	0.36	0.52	0.36	0.52	0.36
open6590	fraction of years between 1965 and 1990 that economy	0.55	0.45	0.55	0.45	0.55	0.45
	number of countries	**48**		**48**		**48**	

[a] Please see Annex 2 for the detailed explanation on how physical capital per capita was calculated.

[b] The adult male survival rate is defined as the probability that a male of age 15 would survive to age 60 given the then-prevailing age-specific mortality rate for males, expressed per thousand males alive at age 15. (i.e. **asr** is 1000 minus 45q15, the more typically available demographic indicator of the probability of dying in the 45 years following the 15th birthday, expressed per thousand.)

[c] The total fertility rate is the expected number of children a woman will have throughout her lifetime at the then-prevailing age-specific fertility rates.

Annex Table 2.2. Determinants of Income Levels and Rates of Technical Progress, 1960-2000

Independent Variable	53 Countries		New: 48 countries 1960-2000	
	10	13	10a	13a
I. Time-invariant determinants of income level:				
constant	1.55	20.07	3.28	19.41
	(0.98)	(5.15)	(4.57)	(5.65)
tropics	-0.39	-0.32	-0.09	0.00
	(3.26)	(2.49)	(1.12)	(0.03)
II. Time-varying determinants of income level:				
ln physical capital per capita	0.38	-2.06	0.48	-1.84
	(11.86)	(3.85)	(13.06)	(3.78)
adult education level	0.04	0.03	0.03	0.02
	(2.90)	(2.33)	(2.06)	(1.71)
ln adult survival rate	0.50	-2.40	0.14	-2.38
	(2.13)	(3.95)	(1.26)	(4.63)
ln total fertility rate	-0.04	-0.11	-0.17	-0.16
	(0.78)	(1.79)	(2.66)	(2.69)
interaction of ln physical capital per capita		0.38		0.36
and ln adult survival rate		(4.65)		(4.95)
III. Determinants of technical progress:				
constant (common across countries)	-0.012	-0.005	-0.002	-0.00003
	(3.83)	(2.16)	(1.17)	(0.03)
coastal	0.009		0.004	
	(2.40)		(2.41)	
open6590	0.017		0.006	
	(5.97)		(3.63)	
<u>Model Statistics</u>				
Within-country variance reduction[a]	90%	89%	87%	88%
Between-country variance reduction[a]	83%	86%	86%	87%
Number of parameters estimated	13	12	13	12
Deviance[b]	-329	-313	-105	-120

[a] The variance reduction numbers indicate the percentage of the between- or within-country variance found in Model 5 that is explained with the indicated model. Based on Model 5, 8% of the variance in the dependent variable is within-country and 92% is between-country.

[b] "Deviance" is twice the negative log-liklihood value associated with the maximum likelihood parameter estimates. The larger the deviance, the poorer the fit.